Research on Effects of RF Emissions on Aircraft Safety

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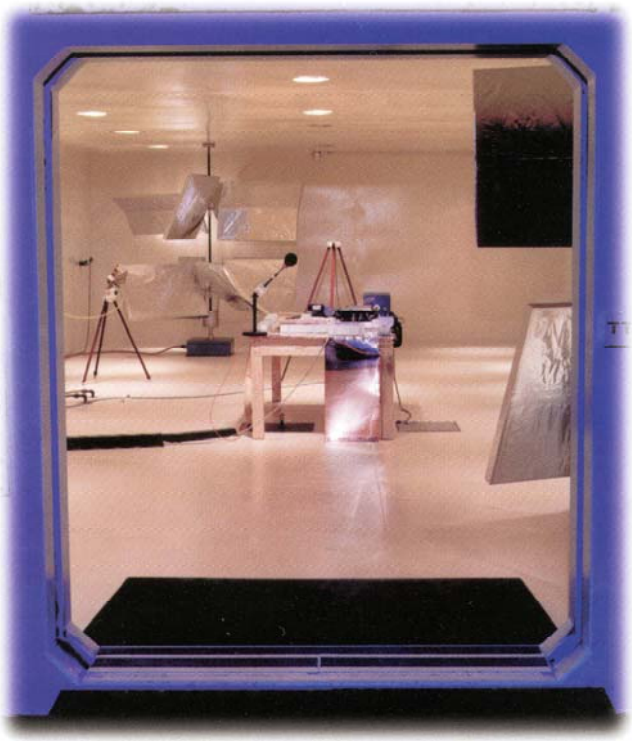
Outline

- HIRF Facility Overview & Capabilities
- RF Emission Measurements
- Path Loss Mesurements
- Interference Threshold Measurements
- Summary

Objective

- **To assess, improve and develop methodologies and capabilities for evaluating immunity of avionics equipment high intensity radiated field (HIRF) and lightning**



HIRF Laboratory Test Capabilities

- High Intensity Radiated Field Testing
- State of the art facility and instrumentation
- Best field uniformity known for reverberation chambers as characterized by NIST
- Three reverberation chambers
  - Also have access to a semi-anechoic chamber and a GHz Transverse EM Cell (GTEM)
- Multiple chambers testing – simultaneous testing different components of a system to different environments
- Achievable field strength 1500 - 3000 V/m
- RF Power amplifiers include (minimum performance):
  - 10 kHz – 250 MHz : 2000W CW, 4000W Pulse
  - 0.1 – 1 GHz: 1000W CW/Pulse
  - 1 – 4 GHz: 200 W CW (2 each)
  - 4 – 18 GHz: 200 W CW
  - 1 – 18 GHz: 1000W Pulse
- Airframe shielding effectiveness measurement

Lightning Indirect Effects Capabilities

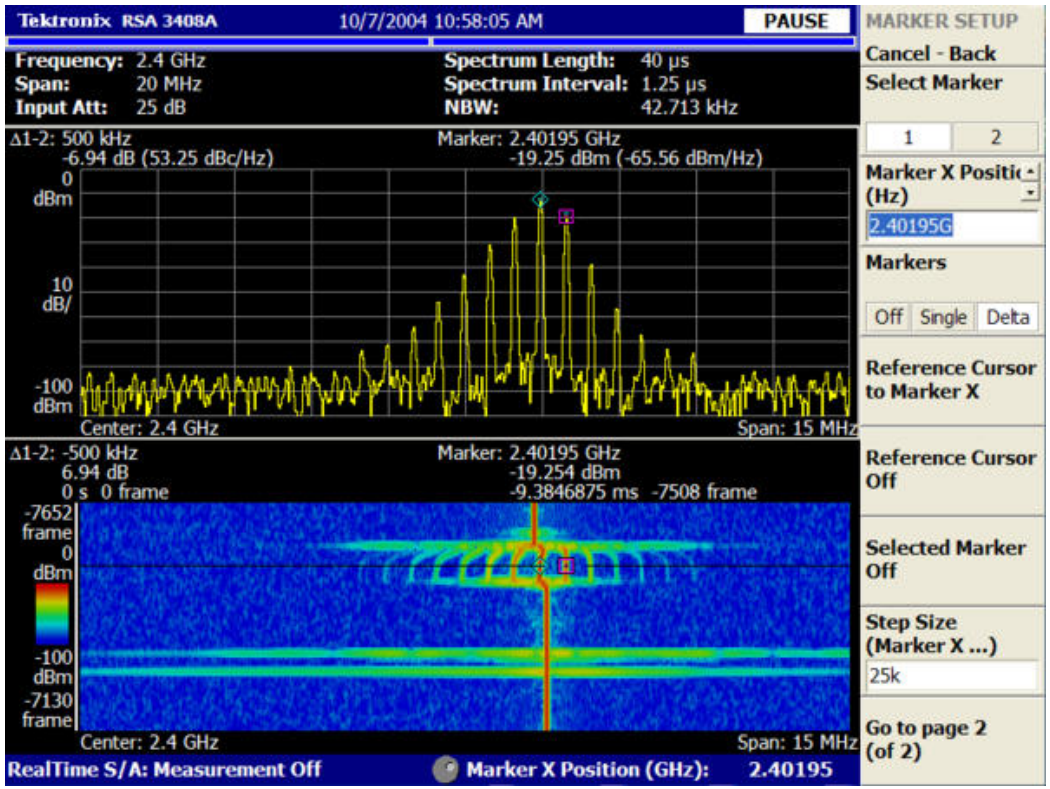
- Lightning indirect effects (induced)
  - Single stroke, multiple strokes, multiple bursts
  - DO-160 test levels, waveforms and patterns
  - Programmable to produce Boeing & Airbus patterns
  - Software automation and remote control
  - COTS – Easy to maintain
  - Very few test sets worldwide. Customers include Boeing and Airbus
- Induced surface current measurement capabilities
  - Low frequency network/spectrum/impedance analyzer
  - Surface current probes
  - Capability developed for measuring surface current on composite materials

Single and Multiple Strokes

Multiple Bursts

Recently Acquired Capabilities

- Tektronix Real-Time Spectrum Analyzer
  - 8 GHz Limit
  - Waterfall display with deep storage
  - Very fast (microseconds sweep) for up to 36 MHz span



Recent Research Activities

- Active Radio Frequency Identification (RFID) Devices Interference Assessment for aircraft radio com/nav systems (FAA)
- Airplane RF coupling measurements and analysis on B757's, B747's and B737's, regional jet's and General Aviation com/nav systems - TCAS, LOC, GS, GPS, VHF Comm to assess effect on systems and mitigation techniques to determine Interference Path Loss (IPL) and Personal Electronic Devices (PEDs) threat locations
- Contributed significantly to RTCA/SC202 committee to develop guidelines for use of PEDs on aircraft
- Customized EMI tests
  - Air Force Research Lab on four test articles – actuators and flight control computer
  - Honeywell Recoverable Computer Systems, Safety Critical Avionics Systems Branch, RTD

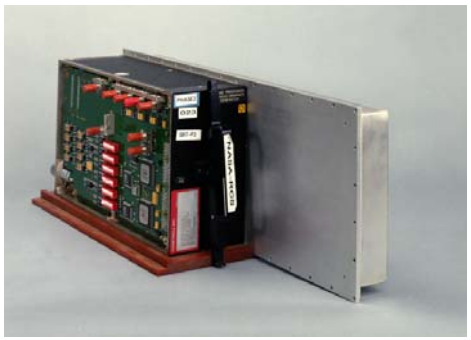
Recent HIRF Publications

- Investigation of Electromagnetic Field Threat to Fuel Tank Wiring of a Transport Aircraft, March 2000, NASA/TP-2000-2-9867. NASA Langley's H.J.E. Reid Award, 2000,
- Ultrawideband Electromagnetic Interference to Aircraft Radios, October 2002 NASA/TM-2002-211949
- Investigation of RF Emissions from Wireless Networks as a Threat to Avionic Systems, October 2002 NASA/CR-2002-211941
- Portable Integrated Wireless Device Threat Assessment to Aircraft Radio Systems , December 2004 NASA/CR-2004-213513
- Third Generation Wireless Phone Threat Assessment for Aircraft Communication and Navigation Radios , March 2005 NASA/TP-2005-213537, IEEE EMC Conference (Third Place Best Conference Paper)
- Portable Wireless LAN Device and Two-Way Radio Threat Assessment for Aircraft Navigation Radios, July 2003 NASA/TP-2003-212438
- Evaluation of Mobile Phone Interference with Aircraft GPS Navigation Systems, 2004 NASA/TP-2004-213001

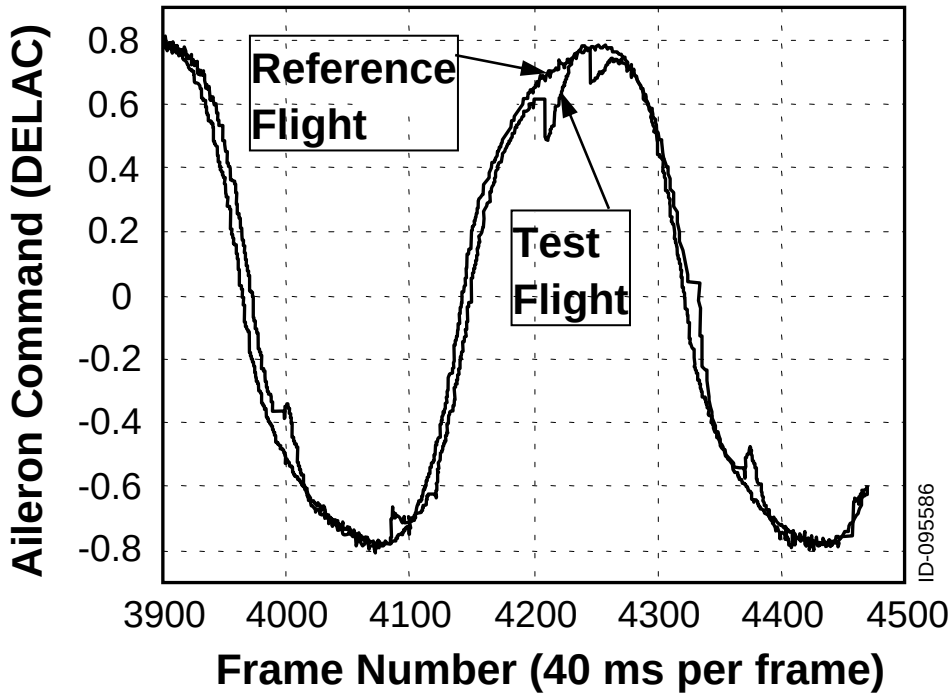
HIRF Immunity Testing

Recoverable Computer System (RCS) Evaluation

NASA/Honeywell Recoverable Computer System

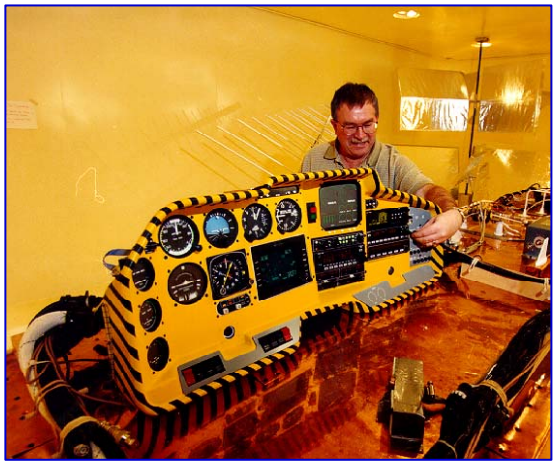


NASA/Honeywell RCS in HIRF Chamber



RCS Recovery Triggered, Multiple Internal Faults (f=640 MHz, E=850 V/m)

Evaluation and Enhancement of HIRF and Lightning Protection Kit



Measurement of Field Attenuation Due to Airframe

PED Coupling to Aircraft Systems

- *(EUROCAE WG-58 and RTCA SC-202)*

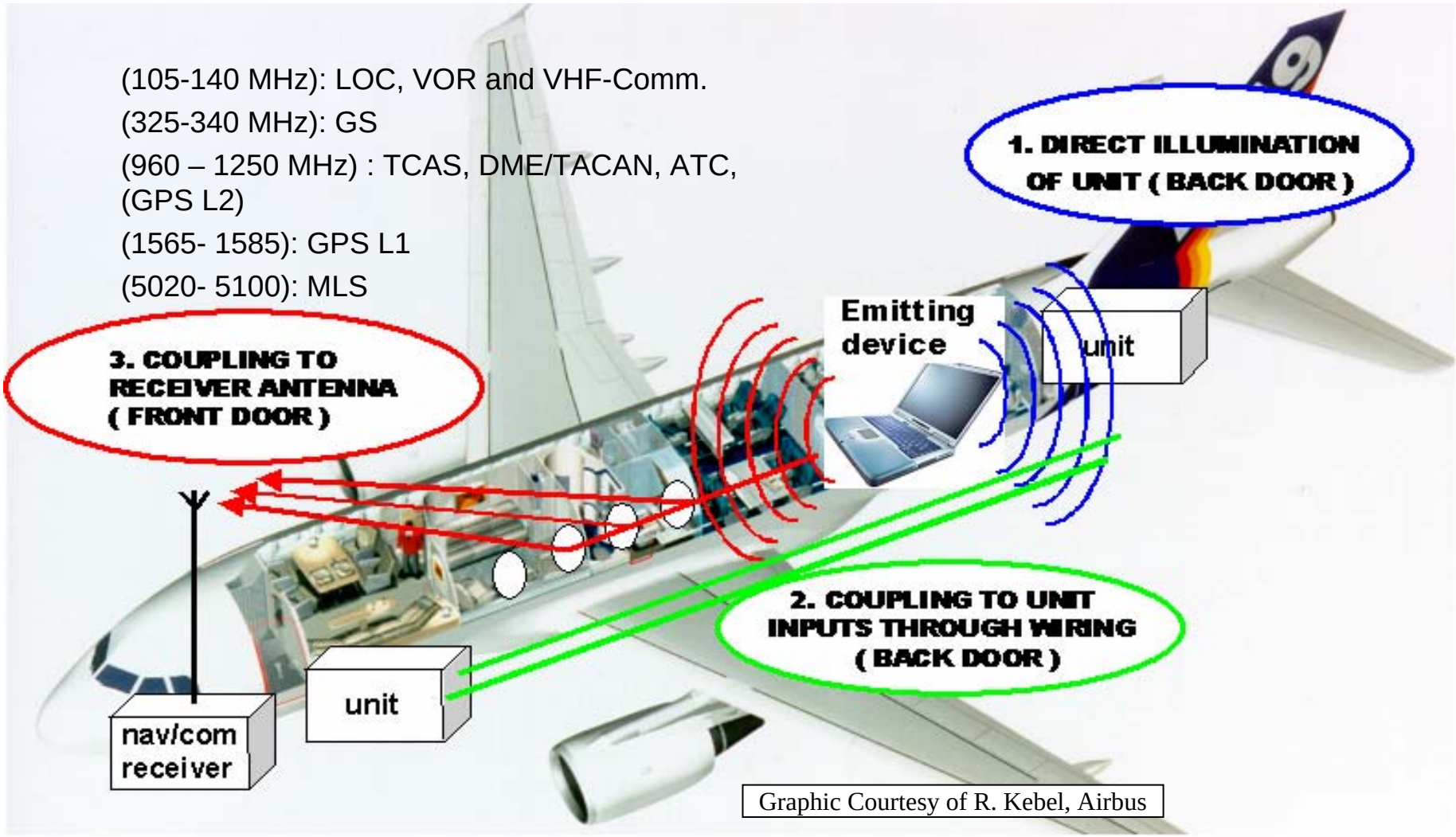
(105-140 MHz): LOC, VOR and VHF-Comm.

(325-340 MHz): GS

(960 – 1250 MHz) : TCAS, DME/TACAN, ATC, (GPS L2)

(1565- 1585): GPS L1

(5020- 5100): MLS

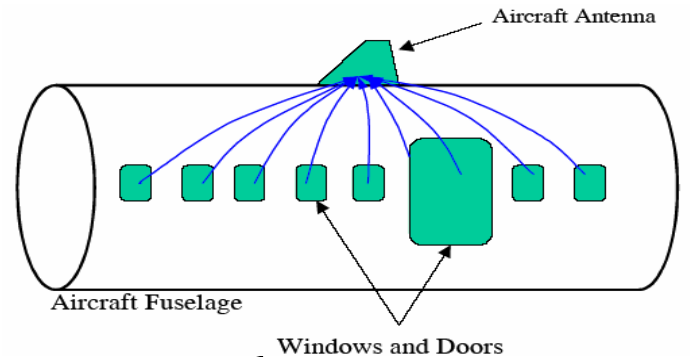


Graphic Courtesy of R. Kebel, Airbus

–Assess the risk of in-band on-channel interference to aircraft radio receivers from Portable Electronic Devices (PEDs)

Source Emissions
(Wireless Devices)

Interference Path Loss (IPL)
(Aircraft Fuselage)



Victim Interference Thresholds
(Nav. & Com. Radio Receivers)

Req. IPL (dB) >= Emissions (dBm) – Interference Thresholds (dB)

Supplemental IPL = Req. IPL (dB) – Measured IPL (dB)

Wireless Devices Evaluated

- 2nd Generation (2G) Wireless Phones
  - GSM (Europe: 900 MHz Band)
  - CDMA (US: 850 MHz Band)
- 3rd Generation (3G) Wireless Phones
  - GSM/GPRS
  - CDMA2000
  - Operating in US Cellular (850 MHz) and PCS (1900 MHz) Bands
- Wireless LAN Devices
  - IEEE 802.11a (5 GHz Band)
  - IEEE 802.11b (2.4 GHz Band)
  - BlueTooth (2.4 GHz Band)
  - Two-way Radios (462 – 468 MHz)
    - Family Radio Service (FRS)
    - General Mobile Radio Service Radios (GMRS)
- Radio Frequency Identification (RFID)
  - Active Tags (300 MHz – 2.5 GHz)

Wireless Phones and Test Modes

GSM/GPRS Phones

- Test modes for GSM and CDMA include:
  - **Voice** Mode
  - **Data** Modes. Three or more different data rates
  - **Cellular** and **PCS** Bands
  - **Five Frequency Channels per band**,
    - Equally spaced across the band
  - Test at **maximum phone transmission power**
  - Also Include **Idle mode** and **Idle-without-a-BSS-signal mode**

CDMA Phones

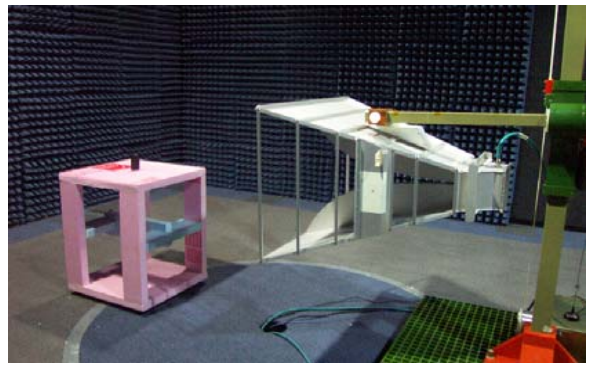
Wireless Techn	No. of Devices	No. of Test Cases Per Device	No. of Test Bands	Total No. Test Cases
GSM	17	21	5	**1785**
CDMA	16	21	5	**1680**

2G Phone Emission

- **Objectives:**

  Develop a radiated emission measurement process for CDMA and GSM wireless phones. Provide a preliminary risk assessment for their potential interference to aircraft Localizer, Glideslope, VOR and GPS radio receivers

- **A Few Details:**
  - Tested in semi-anechoic and reverberation chambers
  - Phones operated in different operating modes
  - Compile interference path loss and receiver interference threshold data
- **Key Results/Findings**:
  - Semi-anechoic and reverberation methods comparability
  - Aircraft-band emissions from the tested phones were insufficient to be of concerns
  - Demonstration of intermodulation products in aircraft bands for phones in near proximity. Intermodulation products in aircraft bands with other wireless technologies are possible
  - Demonstration of wireless connectivity in a reverberation environment



Semi-anechoic chamber test

Multiple phone interaction

GSM & CDMA base-station simulator

3G Phone

- Extension of earlier tests of 2G phones
  - To include PCS band phones
  - Newer generation data capable phones
- 33 phones: **17 GSM/GPRS, 16 CDMA 1XRTT phones**
- Measurements performed in reverberation chambers
- Phone controls using a new **Agilent Base-Station Simulator**
- Many combinations of **Filters**
  - In **Wireless Path**: to block noise from the Base Station Simulator from enter into the chamber
  - In **Measurement Path**: to block wireless signals from causing intermodulation in the receiver and pre-amps
- Results compared against
  - Spurious Emissions from Laptops/PDAs
  - FCC Part 22 & 24 for Wireless Phones and FCC Part 15 for non-transmitting devices
  - RTCA/DO-160D Category M Limits for aircraft installed equipment

Wireless LAN Devices

- Spurious Emissions Measured for:
  - **Six** 802.11a Devices (5 GHz band)
  - **Seven** 802.11b Devices (2.4 GHz band)
  - **Six** BlueTooth Devices (2.4 GHz band)
  - **14 FRS & GMRS Two-way Radios** (462 – 468 MHz band)
- Measured Data Compared against :
  - Spurious emissions from existing Laptops/PDAs
  - FCC Part 15
  - RTCA/DO-160 aircraft equipment emission limits

802.11A

802.11B

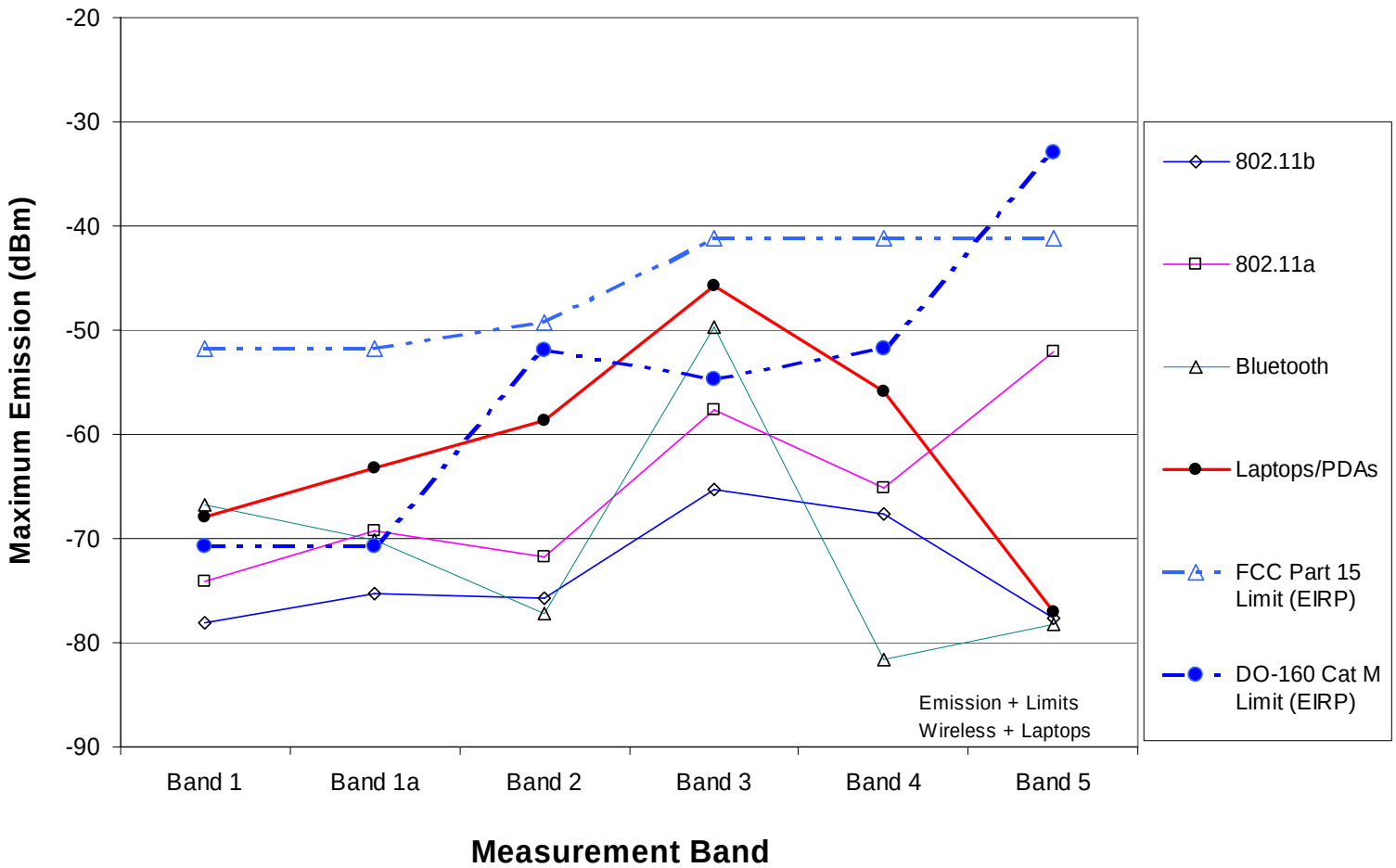
Bluetooth

FRS Radios

GMRS Radios

WLAN Device Maximum Emissions

WLAN



Radio Frequency Identification (RFID) Active Tags

Identec

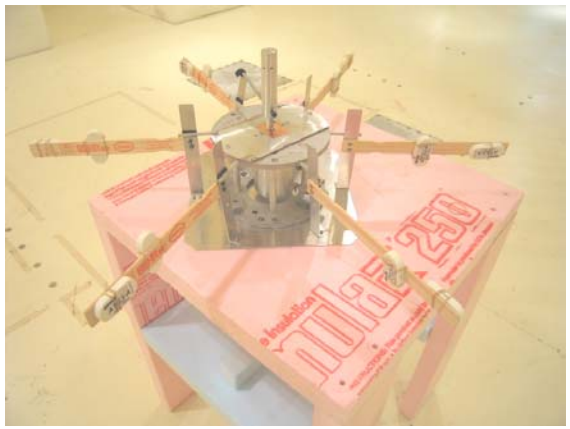
Sovereign Tracking Systems

WhereNet

RF Code

Savi

- **Main Tag Types:**
  - Beacon
  - Interrogated
  - Motion



Shaker for Motion Tags

Testing Beacon Tags

Preliminary Findings

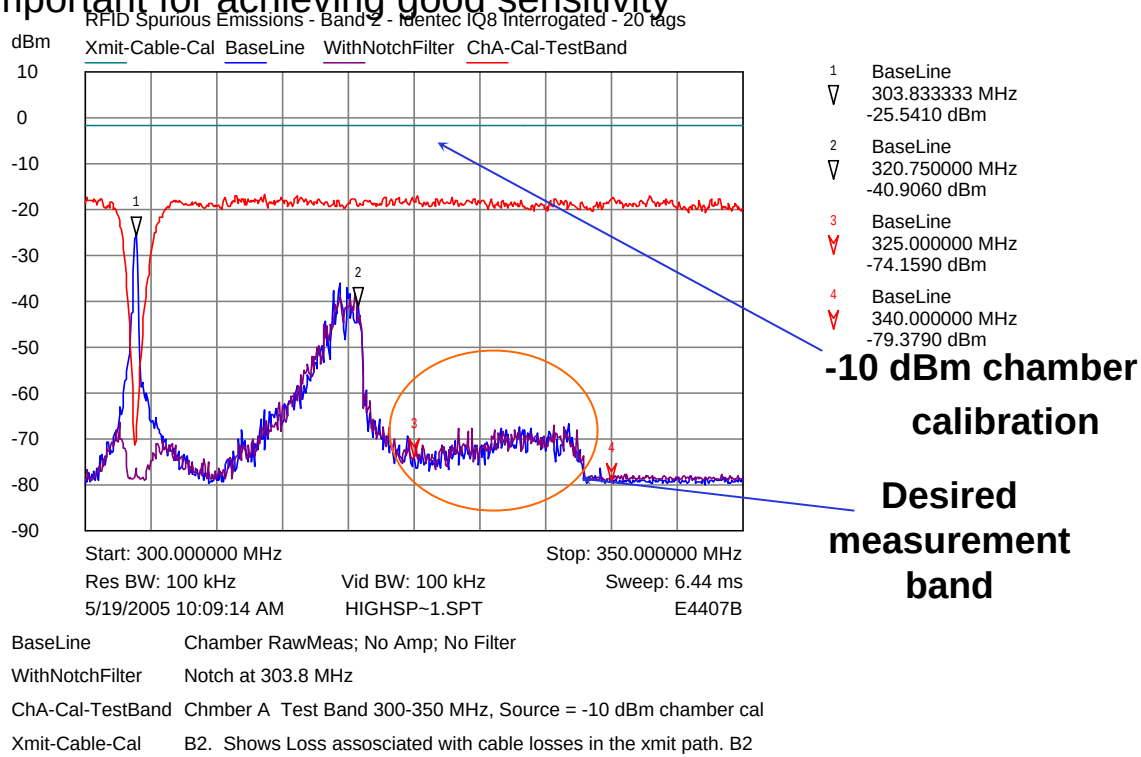
- Many tags are noisy
  - Much worse than other wireless devices tested
  - Possibly due to low cost and lack of required performance standard
  - Due to high noise levels and harmonics
    - Filters are very important for achieving good sensitivity

Example:

RF Code

2 seconds

Beacon Tags



BaseLine	Chamber RawMeas; No Amp; No Filter
WithNotchFilter	Notch at 303.8 MHz
ChA-Cal-TestBand	Chmber A Test Band 300-350 MHz, Source = -10 dBm chamber cal
Xmit-Cable-Cal	B2. Shows Loss assosciated with cable losses in the xmit path. B2

Path Loss- Computing Required IPL

Class A- Industrial Class B- Residential 15 209- Transmitters Licensed T-Peds- Cell Phones

VHF-Com

a) Required Minimum Path Loss (dB) = Emissions (dBm) - Thresholds (dBm)

		FCC-15.109		FCC-15.209	Licensed T-PEDs
		Class A	Class B		include 2-way radio
		EIRP (dBm)	EIRP (dBm)	EIRP (dBm)	ERPor EIRP (dBm)
Receiver Interference Threshold (DO-199) (dBm)		***-41.2***	***-51.7***	***-51.7***	***-13***
Typical	***-107***	**65.8**	**55.3**	**55.3**	**94**
Worst Case	***-107***	**65.8**	**55.3**	**55.3**	**94**

In VHF-Com Band/LOC/VOR

FCC-15.109

Class A 150 uV/m @10m

Class B 150 uV/m @3m

FCC-15.209 150 uV/m @3m

Licensed T-PEDs -13 dBm

b) Minimum IPL (MIPL) - VHF-Com - From Existing Aircraft

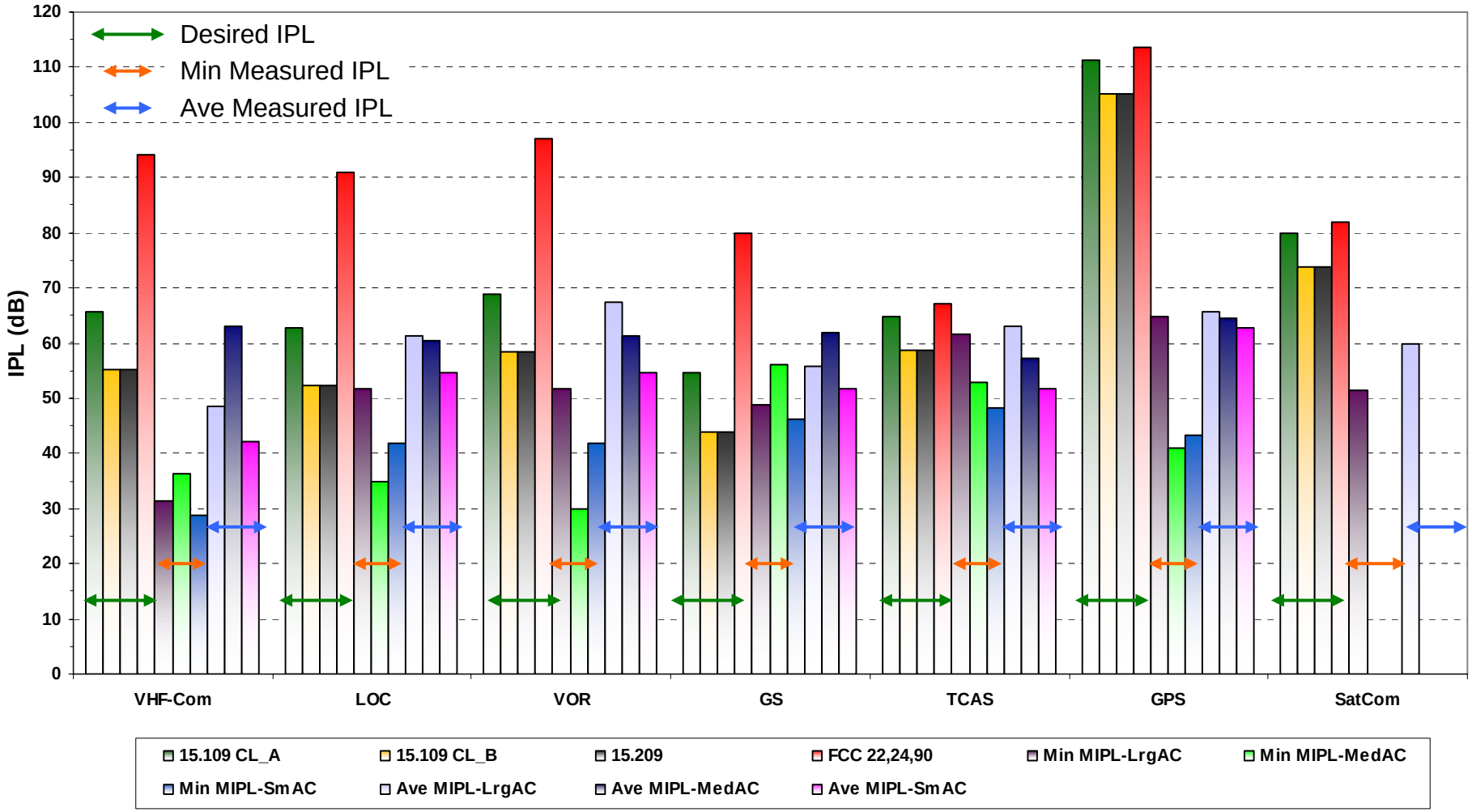
(From NASA WLAN Report -July 2003c- pages 94-95)

	Large Aircraft	Medium Aircraft	Small Aircraft
Lowest MIPL	**31.5**	**36.3**	**28.7**
Ave MIPL	**48.6**	**63.1**	**42.2**
Highest MIPL	**71.5**	**76**	**50.9**

Desired IPL for FCC Emission Limits

[Desirable IPL for FCC Emission Limits] vs [Measured AC IPL] Comparison

[Data Computed with FCC Part 15 Emissions: Quasi-peak for f<1GHz, Peak for f>1GHz (20 dB Peak Limit/Ave Limit)]



Summary of Path Loss Measurements

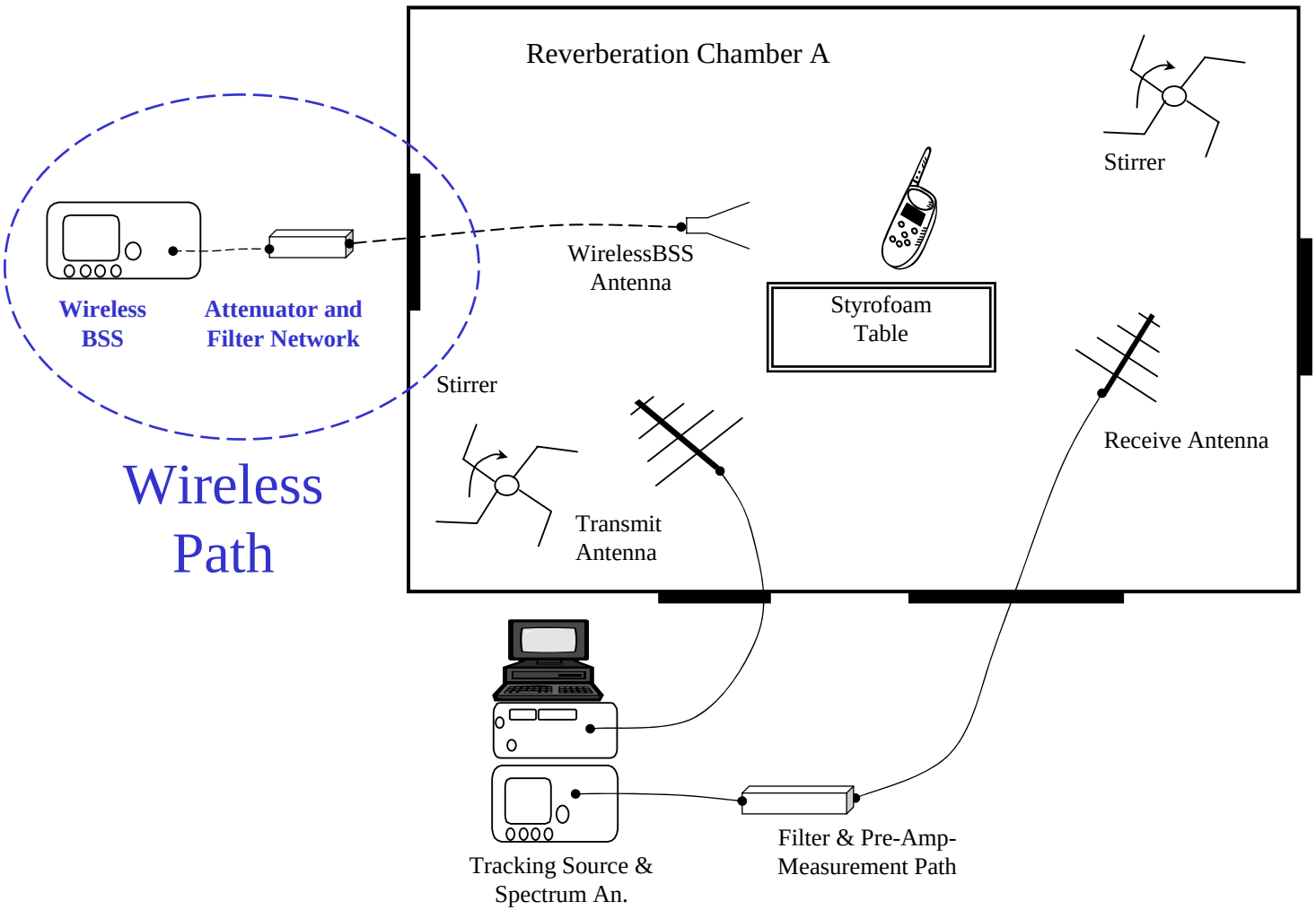
- The attenuation needed to have a “PED proof” certified aircraft vs FCC class A (or even B) devices is very difficult to achieve for all receivers
  - 10 to 20dB for ATC/TCAS, Glide Slope, DME
  - 20 to 40 dB for VHF, VOR, Localizer
  - 50 to 70 dB for GPS at 1.6 GHz
- 8 additional aircraft have been measured in 2006
- Results will be reported in NASA TP “Small Aircraft RF Interference Path Loss Measurements” & RTCA document (2007)
- Follow on experiments will measure propagation path to determine mitigation strategies for future aircraft designs (2008)
- Database containing path loss measurements being populated. (2009)

Summary

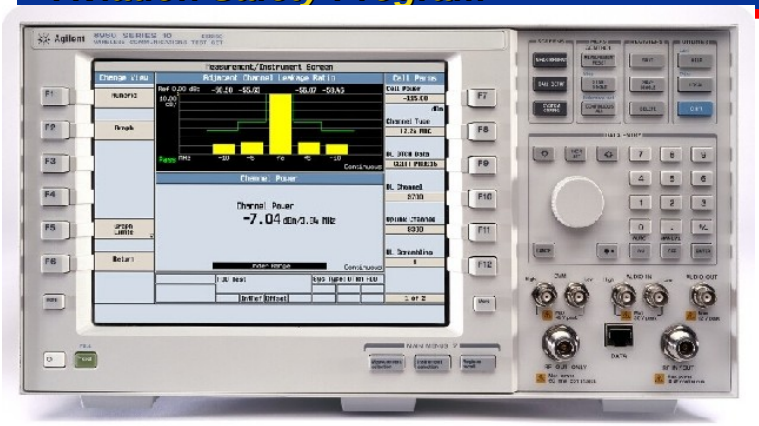
- We have extensive measurement and analysis capabilities to address interference to aircraft radio receivers
- Results of our work were cited extensively in design standards documents
- Highly positive feed back from the FAA and the industry
- Would like to continue and expand the work to address issues of concern to the FAA and the industry on aircraft interference

- Back UP Slides

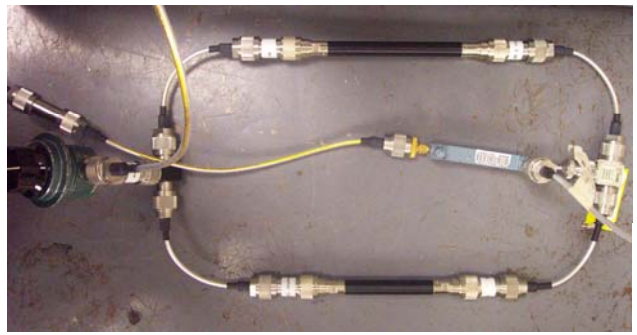
Test Setup


Reverberation Chamber A
Stirrer
WirelessBSS
Antenna
Styrofoam
Table
Wireless
BSS
Attenuator and
Filter Network
Stirrer
Receive Antenna
Wireless
Path
Transmit
Antenna
Tracking Source &
Spectrum An.
Filter & Pre-Amp-
Measurement Path

Wireless Path



Base Station Simulator

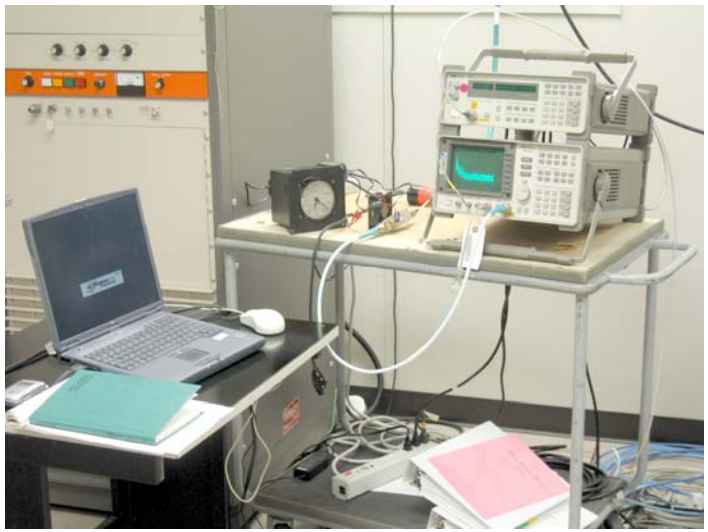


Filters – Wireless Path

- Agilent 8960-Series 10 Wireless Communication Test Set (Hardware)
  - **Multi-format** capability
  - **Format-flexible** architecture
- E1991B Test Application Suite (Software)
  - Capable of Testing AMPS, TDMA, CDMA IS-95, **CDMA2000**, 1xEV-DO, **GSM/GPRS**, EGPRS (EDGE), WCDMA devices
- Filter Network:
  - Parallel filters pass only Cellular and PCS signals
  - Allows band switching between Cellular and PCS bands
  - Necessary for testing dual-band phones

Test Setup

Wireless Path Equipment



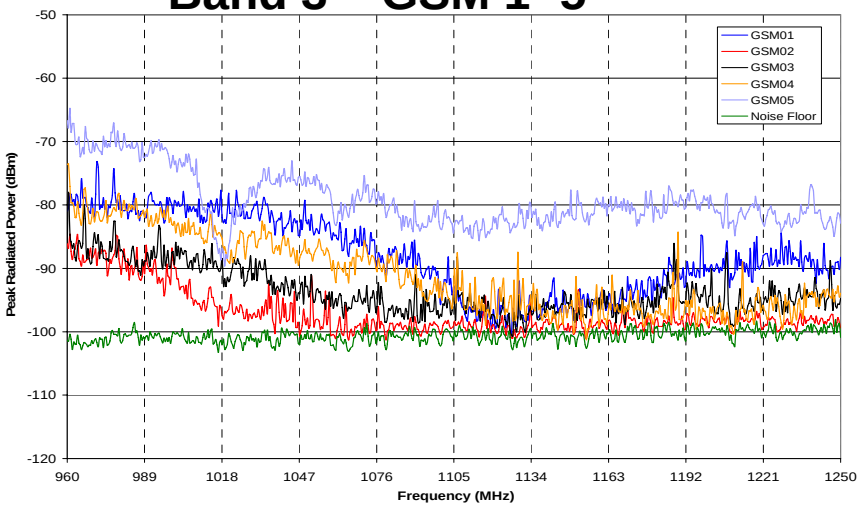
Measurement Path Equipment

Chamber A Testing

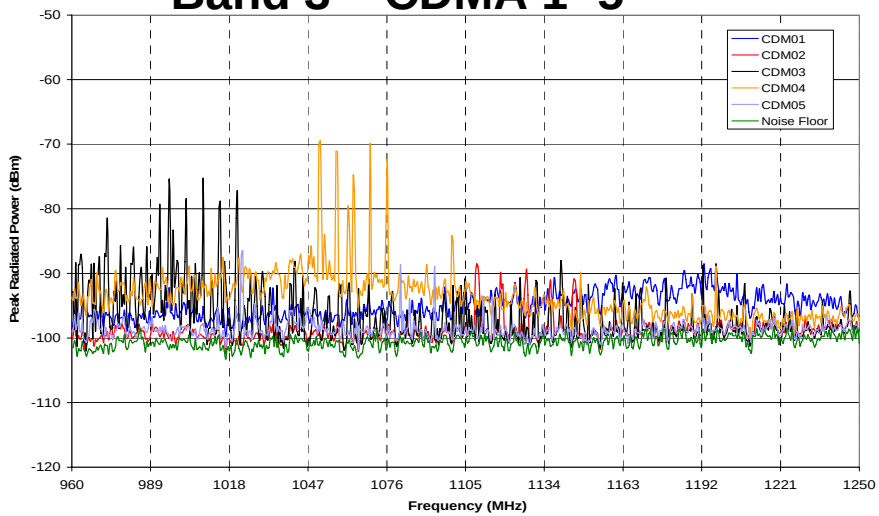
Filters and Pre-Amplifiers in Measurement Path

Result Sample and Summary

Band 3 – GSM 1- 5



Band 3 – CDMA 1- 5



Result Summary